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An Environmental Decision Support System Based on a Multidimensional Prototype

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Abstract: The present study utilizes the principles and data provided by the Environmental Priority Strategies (EPS) methodology in order to create a multidimensional prototype, which intends to assist the damage assessment process in this kind of projects. The EPS system, based on Life Cycle Assessment (LCA) methodology, is developed to help designers and product developers in finding which one of two or more product concepts has the least impact on the environment. In this context, the multidimensional model combines the dimensions: (i) Damage Categories, further analyzed to Impact Categories, (ii) Pollutants, (iii) Effected Media and (iv) Products, in order to present the knowledge built into the EPS system from various angles. The main advantages of the proposed model are its simplicity and flexibility. Specifically, the samples presented give an indication of the capabilities of the model that is an Environmental Decision Support System (EDSS). When using the model environmental experts can come to very useful conclusions by manipulating any combination of dimensions and measures.

Key words: Environmental Decision Support System, Multidimensional Database, Damage Assessment, Environmental Priority Strategies

INTRODUCTION

The EPS Concept: The EPS system, (EPS stands for Environmental Priority Strategies in product design) was developed to meet the requirements of an everyday product development process, where the environmental concern is just one among several others. The main goal of the EPS system is to assess the added value from all types of impacts. This requirement is partly a consequence of the demand on the system to be operative. It is considered unrealistic to take for granted that a product developer, who already has many technical and economical considerations to make, would be able to handle several different impact numbers. He or she ought to have the possibility of choosing the degree of complexity and detail in the information [1, 2]. The development of the EPS system is made in a top-down manner. Starting with the requirements expressed in the formulation of the goal, various methods are developed to produce the data and indices needed for the analysis. In order to make the system operative a default method including a database is developed. The default database could be used in the beginning of the product development phase and the indices gradually exchanged as more specific knowledge of material and processes used develop [2, 3]. The EPS methodology is based on the LCA (Life Cycle Assessment) concept. The prime purpose of LCA is to support the choice of different (technological) options for fulfilling a certain function by compiling and evaluating the environmental consequences of these options [4, 5]. LCA studies have four main elements: (a) setting the goals and scope for the study; (b) conducting a life cycle inventory analysis; (c) carrying out an impact assessment; and (d) making an interpretation of the results. The task in the Life Cycle Inventory Analysis (LCI) stage is to trace (ideally) all inputs to and outputs from every stage in the life cycle back to the associated terminal inputs from and outputs to nature (the environment). The flows may usefully be segregated into inputs of materials and outputs of wastes to air, land and water [6].

Relational and Multidimensional Databases: Codd [7] invented the term Online Transaction Processing (OLTP) and proposed 12 criteria that define an OLTP (relational) database. His terminology and criteria became widely accepted as the standard for databases used to manipulate the day-to-day operations (transactions) of an organization. In the 1990s, Codd invented the term Online Analytical Processing (OLAP) and proposed 12 criteria to define an OLAP (multidimensional) database. Although the criteria did not gain wide acceptance, the term OLAP is used to describe databases designed to facilitate decision-making (analysis) in an organization [7]. A relational database consists of many related two-dimensional tables of data. Being two-dimensional, a table is of m x n size, where m is the number of different attributes that it holds and n is the number of logical entries (records). Therefore each value stored in a table is defined by its (m,n) coordinates. The meta-data about the attributes (description, data type, field size etc.) are stored in a different location (data repository) than the actual data [8]. A multidimensional database is used to store multidimensional aggregates of data. It consists of the multidimensional data and the hierarchical trees of interrelated attributes (dimensions). Similarly to a relational table, a multidimensional database can also store various attributes of data (quantity, value, cost etc.), called measures, which are also treated as one additional dimension. Therefore, similarly to relational tables, each multidimensional database consists of (a) data with coordinates (one per dimension (d1-dn), plus one for the measures (m)) of the type (d1,d2,d3,d4,….,dn,m), (b) hierarchical trees (one per dimension) and (c) measures [9].

The Necessary Steps in Order to Transform EPS Raw Data to Multidimensional Data: The data provided by the EPS system have to be transformed in a three-step process (Fig. 1) before they can be fully utilized for analysis [10]. The steps are:

* Normalization- Design of Relational Database (RDB). Design relational tables with unique keys and avoid repetitions and loss of values when logical entries are deleted.
* Design of multidimensional cube. Decide which dimensions and measures will be included in the model.
* Data Quality. Isolate and correct all problems caused by wrong values of the raw data.

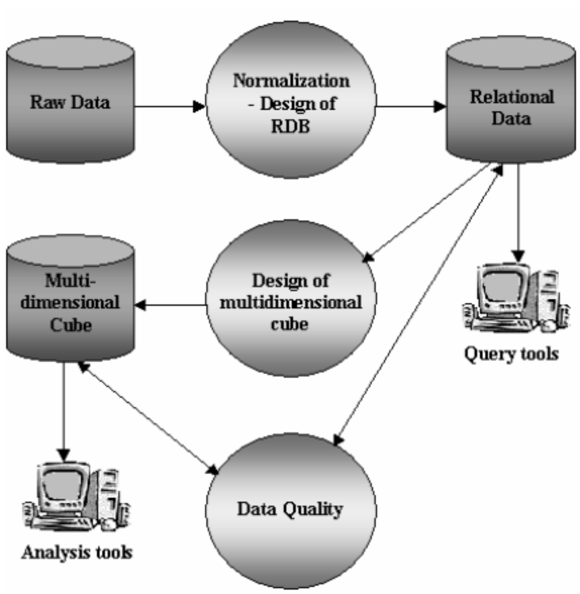

Fig. 1: The Transformation Steps towards a Multidimensional Database

Although the final objective of the model is the design and implementation of the Multidimensional cube, which can be analysed using multidimensional analysis tools, the relational database (RDB) can also be exploited by end-user query tools that can relate relational tables and produce end-user reports.

MATERIALS AND METHODS

Based on the three basic implementation steps, the implementation of the multidimensional model involved the following steps: (1) transformation of the EPS raw data into a relational model, (2) from the relational to the multidimensional model and (3) data quality.

Transformation of the EPS Raw Data into a Relational Model: The EPS system provides three sets (that will be transformed to relational tables) of data in the form:
Pollutants per impact category with details:

* Impact Category (e.g. Life Expectancy)
* Unit of measure of impact category (e.g. Person-years)
* Effected Media (e.g. Air)
* Pollutant - Chemical Compound (e.g. 1-butene)
* Unit of measure of pollutant (e.g. kg - kilograms) and
* Environmental Load Factor of pollutant on impact category

Impact categories per damage category with details:

* Damage Category (e.g. Human Health)
* Unit of measure of damage category (e.g. ELUs/person-year)
* Impact Category (e.g. Life Expectancy)
* Unit of measure of impact category (e.g. Person-years)
* Environmental Load Factor of impact category on damage category

Weighting measured in Environmental Load Units (ELUs) with details:

* Damage Category (e.g. Human Health)
* Environmental Load Factor of damage category on weighting

And in order to give an example, 1 kg of 1-butene has an impact on air, 1.83×10^{-5} person-years impact on Life Expectancy (according to the data of relational Table 1), 1.5555 (0.0000183x85000) ELUs/person-year impact on Human Health (according to the data of relational Table 2) and 1.5555 (1.5555x1) ELUs weighted (according to the data of relational Table 3).
The model implemented considers an additional set (relational table) of data for the products in the form:

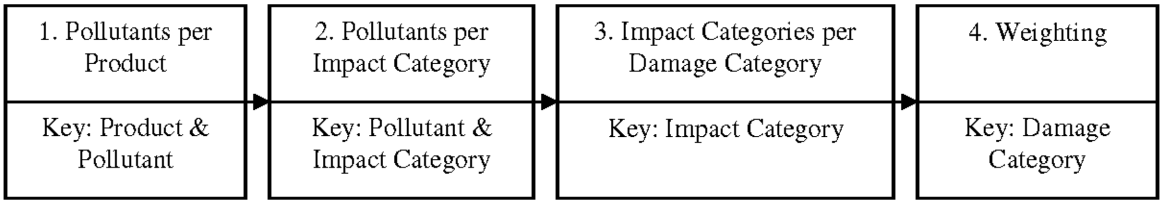

Fig. 2: The Relational Model

Table 1: The Dimensions of the Multidimensional Cube

Dimensions	Environmental categories	Pollutants	Effected media	Products
Level 1	Damage categories	Pollutants-chemical compounds	Effected media	Products
Level 2	Impact categories			

Table 2 : Pollutants Vs Damage Categories

Sum of weighting	Damage category			
Chemical compound	Biodiversity	Human health	Abiotic stock resource	Ecosystem production capacity
1-pentene				-0,00516
1,1,1-trichloroethane	0,01529	1,136		0,001185
1,2,3-trimethylbenzene	0,01529	1,8885		0,50484
1,2,4-trimethylbenzene	0,01529	1,8705		0,49434
1,3,5-trimethylbenzene	0,01529	1,88		0,50034
1,3-butadiene	0,01529	9,9871		0,72514

Table 3: Pollutants Vs Effected Media

Sum of weighting	Damage Category				
Chemical compound	Air	Non mat.	Raw	Soil	Water
1-pentene	-0,00516				
1,1,1-trichloroethane	1,152475				
1,2,3-trimethylbenzene	2,40863				
1,2,4-trimethylbenzene	2,38013				
1,3,5-trimethylbenzene	2,39563				
1,3-butadiene	10,72753				
1-butene	2,57584				
1-pentene	2,46229				
2,4,5-T (agr.)				0,35677	
2,4-D (agr.)				0,35677	

Table 4: Pollutants Vs Damage and Impact Categories

Sum of weighting		
Chemical compound	Damage category	Impact category
1-pentene	Ecosystem production capacity	Wood growth capacity
	Ecosystem production capacity total	
1-pentene total		
1,1,1-trichloroethane	Biodiversity	Species extinction
	Biodiversity total	
	Human health	Life expectancy
		Severe morbidity
	Human health total	
	Ecosystem production capacity	Crop growth capacity
		Wood growth capacity
	Ecosystem production capacity total	
1,1,1-trichloroethane total		

Pollutants per product with details [11]:

* Product (e.g. Glass Bottle 250 mL)
* Unit of measure of product (e.g. mL)
* Quantity of product (e.g. 4,000 bottles as all figures are for 1,000 L)
* Pollutant- Chemical Compound (e.g. SO_2- Sulphur Dioxide)
* Quantity of pollutant found in the quantity of the product, measured in the unit of measure of the pollutant found in relational Table 1 (e.g. 5,693381 kg/1,000 L)

The first step of transformation is from the raw EPS data to a relational model. The model (Fig. 2) consists of four tables. The attributes per table are given in detail above and the primary keys per table are shown in Fig. 2. The first two tables have compound primary keys in order to be unique (since a product might consist of more than one pollutant and a pollutant might appear in more than one impact category). The keys used in order to relate the tables are Pollutant (Table 1 and 2), Impact Category (Table 2 and 3) and Damage Category (Table 3 and 4).

From the Relational to the Multidimensional Model: The multidimensional model considers: (i) the dimensions and (ii) the measures of the multidimensional cube. The dimensions are trees of interrelated data groupings. Only groupings that form a unique hierarchy can be organized into the same tree as multiple levels of the same dimension. The Environmental Categories is an example of a multiple-level dimension (two levels) since according to the EPS methodology each Impact Category can be grouped into one and only one Damage Category. This hierarchy appears in relational Table 2 and is represented as a tree in Fig. 3. The remaining three dimensions: (i) Pollutants (chemical compounds), (ii) effected media and (iii) products are single level dimensions since there is no hierarchical relationship between them. The measures associated with the various combinations of data are: (i) Person-years, (ii) Kilograms, (iii) H+eq., (iv) ELU/kg, (v) ELU/Person-year, (vi) ELU and (vii) Weighted (in ELUs).

Data Quality: The major problem encountered, when the relational tables and the multidimensional cube were populated with the raw EPS data, was that of the quality of the data [12]. The problem mainly appeared in relational Table 2 (pollutants per impact category) and had to do with the pollutants (chemical compounds). A slight modification in the name of a pollutant (an additional space or a period) appearing in a pollutant, present into more than one impact

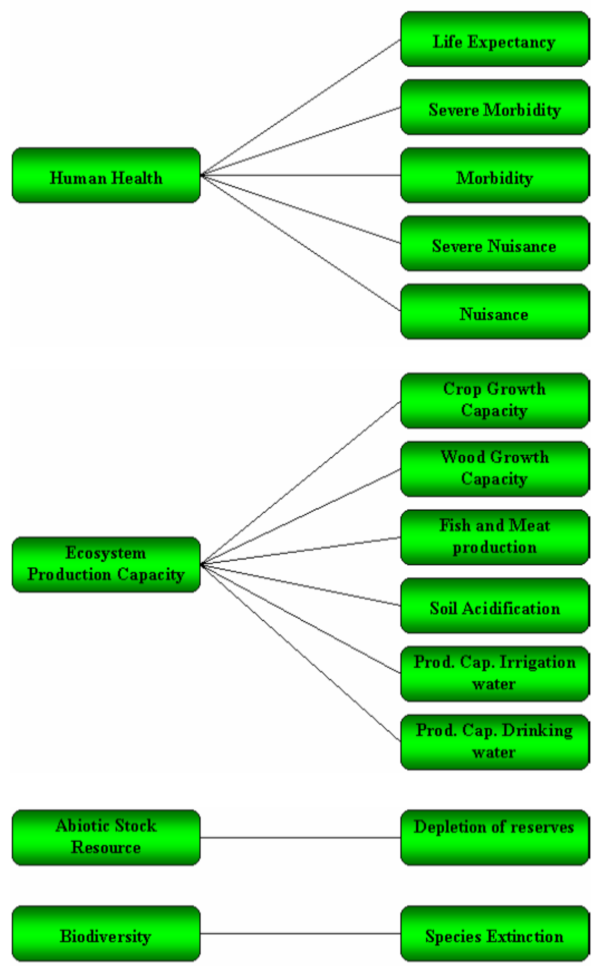

Fig. 3: The Environmental Categories Dimension Tree

categories, resulted in having multiple occurrences of the pollutant with a slightly different name, thus the same pollutant appeared in the reports as two different chemical compounds. The problem was easier to isolate in the multidimensional cube that stores data aggregates. Therefore one report was produced per level per dimension (Table 1): (i) Damage Categories, (ii) Impact Categories, (iii) Pollutants, (iv) Effected Media and (v) Products. All multiple occurrences were (a) located, (b) corrected in the relational database and (c) updated the multidimensional cube. An additional issue, that has to do with data quality, is that the relational tables are not fully normalized. The relational tables Pollutants per Product (relational Table 1) and Pollutants per Impact Category (relational Table 2) are not normalized. They should be broken down in four tables: (i) Products (with product specific details, such as unit of measure of product), (ii) Pollutants (with chemical compounds specific details, such as unit of measure of pollutant), (iii) Pollutants per Product and (iv) Pollutants per Impact Category. The model was intentionally designed with not fully normalized

Table 5: Pollutants Vs Damage, Impact Categories and Effected Media

Sum of weighting			Effected
Chemical compound	Damage category	Impact category	Air
1-pentene	Ecosystem production capacity	Wood growth capacity	-0.00516
	Ecosystem production capacity Total		-0.00516
1-pentene Total			-0.00516
1,1,1-trichloroethane	Biodiversity	Species extinction	0.01529
	Biodiversity total		0.01529
	Human health	Life expectancy	0.748
		Severe morbidity	0.388
	Human health total		1.136
	Ecosystem production capacity	Crop growth capacity	0.006345
		Wood growth capacity	-0.00516
	Ecosystem production capacity total		0.001185
1,1,1-tirchloroethane total			1.152475

Table 6: Products Vs Pollutants and Effected Media

Sum of product weighting		Effected media		
Product	Chemical compound	Air	Water	Grand total
Glass Bottle 250 mL	Ammonia	0,000158989		0,000158989
	Benzene	0,311307078		0,311307078
	BOD		3,68077E-08	3,68077E-08
	COD		5,53603E-08	5,53603E-08
	HCI	0,001666102		0,001666102
	HCL	-0,000279065		-0,000279065
	HF	0,000523334		0,000523334
	N_2O	0,039280911		0,039280911
	NOx	6,169974264		6,169974264
	Particulate (PM10)	23,63293847		23,63293847
	Pb	0,47324166		0,47324166
	SO_2	18,59853925		18,59853925
Glass bottle 250 mL total		49,22735099	9,2168E-08	49,22735108
Grand total		49,22735099	9,2168E-08	49,22735108

relational tables, as the relational database was an intermediate stage in the design of the multidimensional cube, which was the scope of this research.

RESULTS

In Table 1 the dimensions of the multidimensional cube are: (i) Damage Categories, further analysed to Impact Categories, (ii) Pollutants, (iii) Effected Media and (iv) Products. The measures are: (i) Person-years, (ii) Kilograms, (iii) H+eq., (iv) ELU/kg, (v) ELU/Person-year, (vi) ELU and (vii) Weighted (in ELUs). The EPS methodology provides the environmental load factor for the combination of categories: Impact Category and then per Effected Media and Pollutant. The multidimensional cube constructed can present the data of the EPS model from various angles.

In the samples that follow the measure selected was the weighted (in ELUs) so that all numbers provided and the summary data calculated make sense, by being of the same unit of measure. Table 2 shows a sample list of Pollutants Vs Damage Categories, indicating the environmental load of each Pollutant in the various Damage Categories. Table 3 shows a sample list of Pollutants Vs Effected Media, indicating the environmental load of each Pollutant in the various Media. Table 4 shows a sample list of Pollutants Vs Damage Category and Impact Category, indicating the Damage and Impact Category where each Pollutant participates. Table 5 shows a sample list of Pollutants Vs Damage Category, Impact Category and Effected Media, indicating the Environmental Load of each Pollutant per Damage Category, Impact Category and Effected Media. Table 6 and 7 introduce the Product dimension. All figures calculated are for 1,000 L, i.e. 4,000 glass bottles (250 mL) and 2,000 plastic bottles (500 mL). Table 6 shows a sample list of Products Vs Pollutants and Effected Media, indicating the Environmental Load of each Product per Pollutant and Effected Media. Table 7 shows a sample list of Products Vs Damage, Impact Categories and Effected Media, indicating the Environmental Load of each Product per Damage, Impact Categories and Effected Media. Table 8 shows a sample list of Damage and Impact Categories Vs Products, comparing the Environmental Load of two Products in the various Damage and Impact Categories.

Table 7: Products Vs Damage, Impact Categories and Effected Media

Sum of product weighting			Effected media		
Product	Damage category	Impact category	Air	Water	Grand total
Glass bottle 250 mL	Biodiversity	Species extinction	-0,167045196	9,2168E-08	-0,167045104
	Biodiversity total		-0,167045196	9,2168E-08	-0,167045104
	Human health	Life expectancy	47,90966285		47,90966285
		Morbidity	0,713923217		0,713923217
		Nuisance	4,497538622		4,497538622
		Severe morbidity	-4,412588774		-4,412588774
		Severe nuisance	0,47324166		0,47324166
	Human health total		49,18177758		49,18177758
	Ecosystem production capacity	Crop growth capacity	0,297894675		0,297894675
		Fish and meat production	0,101635334		0,101635334
		Soil acidification	0,119383406		0,119383406
		Wood growth capacity	-0,30629481		-0,30629481
	Ecosystem production capacity total		0,212618604		0,212618604
Glass bottle 250 mL total			49,22735099	9,2168E-08	49,22735108
Grand total			49,22735099	9,2168E-08	49,22735108

Table 8: Damage and Impact Categories Vs Products

Sum of product weighting		Product	
Damage category	Impact category	Glass bottle 250 mL	Plastic bottle 500 mL
Biodiversity	Species extinction	-0,167045104	-0,068405812
Biodiversity total		-0,167045104	-0,068405182
Human health	Life expectancy	47,90966285	37,40965403
	Morbidity	0,713923217	0,877983329
	Nuisance	4,497538622	3,754600541
	Severe morbidity	-4,412588774	-2,142523866
	Severe nuisance	0,47324166	
Human health total		49,18177758	39,89971403
Ecosystem production capacity	Crop growth capacity	0,297894675	0,30369716
	Fish and meat production	0,101635334	0,090483443
	Soil acidification	0,119383406	0,103358863
	Wood growth capacity	-0,30629481	-0,316444648
Ecosystem production capacity total		0,212618604	0,181094819

DISCUSSION

The present study proposes a multidimensional prototype based on the EPS framework, which intends to assist the damage assessment process in this kind of projects. The complexity of natural and built systems and our meager comprehension of that complexity make the job of environmental decision-making difficult. For this purpose, methodologies like EPS have been developed in order to assist this decision-making by creating tools aimed at a systematic assessment of environmental performance of product systems. However, these tools, in many cases, incorporate data, which cover a few hundreds of substances, making very difficult to interpret the results of them. In other words, although the benefit is that these results are very detailed, they cannot be used as they are for a deep comparison of the environmental performance of products. For this, a procedure that manipulates appropriately the results seems to be, very often, necessary. This is the aim of the proposed here model. In this context, the multidimensional model combines the dimensions: (i) Damage Categories, further analyzed to Impact Categories, (ii) Pollutants, (iii) Effected Media and (iv) Products, in order to present the knowledge built into the EPS system from various angles. The model allows to combine all the above-mentioned dimensions and measures examining: the impact of the various chemical compounds per damage and impact category in total or per effected media, the chemical compounds affecting each damage and impact category or each effected media, the impact of a specific product on damage and impact categories or on effected media etc. The main advantages of the proposed model are its simplicity and flexibility in manipulating the various dimensions and measures, in order to present the EPS methodology data from various angles and thus support various environmental experts' decisions. Therefore the proposed model can be classified as an Environmental Decision Support System (EDSS) [13] based on the EPS methodology and the samples presented so far give just an indication of its capabilities. When using the model, environmental experts can come to very useful conclusions, as already shown, by manipulating any combination of dimensions and measures.

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